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# EFFECT OF AIRFLOW INTERACTION ON TEMPERATURE AND VELOCITY AT THE BREATHING ZONE OF SEATED PERSON

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## SUMMARY

The impact of airflow interaction on air temperature and velocity measured at the breathing zone (BZ) of a seated person was studied. A breathing thermal manikin was used to resemble the flow of breathing and the free convection flow (FCF) around the human body. Personalized ventilation (PV) supplied flow from front against the face of the manikin increased the complexity of the interaction.

Experiments were performed in a climate chamber where a quiescent environment was maintained. The chair below the manikin was covered with a local air exhaust called Ventilated Cushion (VC), which aimed to weaken the FCF. The personalized flow was supplied isothermally. The manikin was inhaling through the nose and exhaling through the mouth. Instruments with short response time were used to measure temperature and velocity.

The jet exhaled from the mouth increased the temperature and the velocity at the breathing zone compared to FCF alone. The VC could be used to control the strength of the FCF. The PV flow at 0.4 m/s could penetrate the FCF. The results indicated that the exhalation flow were dominant to the PV flow.

**Keywords:** airflow interaction, breathing zone, velocity, temperature, breathing thermal manikin

## 1 INTRODUCTION

Understanding the flow interaction at the breathing zone (BZ) is an important issue because it affects occupant's exposure to the indoor air pollution and the perceived air quality (PAQ).

An upward free convection flow (FCF) is established around occupants when difference exist between the surrounding air temperature and the body surface temperature (Melikov, 2015). Its shape and strength depends on how big is the difference, body posture, clothing, presence of the furniture, etc. The temperature and velocity of the FCF, which transports pollution to the BZ, have been studied (Licina et al., 2015, Licina et al., 2014, Rim and Novoselac, 2009). Exhaled flows with different direction and strength are generated during breathing (Melikov and Kaczmarczyk, 2007).

It has been documented that increase of air temperature, relative humidity and pollution level has negative impact on PAQ (Fang et al., 1998, Melikov and Kaczmarczyk, 2012). Air movement with elevated velocity from front improves PAQ and diminishes the negative impact of elevated temperature, humidity and pollution level (Melikov and Kaczmarczyk, 2012).

Personalized Ventilation (PV), especially when supplied at the breathing zone, is one of the strategies to improve inhaled air quality (IAQ) and PAQ (Kaczmarczyk et al. 2012). Bivolarova et al. (2016) reported on the use of chair placed ventilated cushion (VC) for the removal of bioeffluents generated by a seated person. The VC weakened the FCF and reduced the pollution at the breathing zone. Thus, control of the airflow interaction at the breathing zone will help for providing occupants with clean air for breathing and improve the PAQ.

The complexity of airflow interaction at the breathing zone of a sedentary person has been studied by performing tracer gas concentration measurements (Bivolarova et al., 2017, Kierat et al., 2018).

Understanding the flows is important for their control, and in this way for improvement of the inhaled air quality. The aim of this study was to investigate and understand the interaction of the FCF, the flow of exhalation and PV flow at the breathing zone based on velocity and temperature measurements. The effect of the VC on control of the FCF and thus on the airflow interaction was studied as well.

## 2 METHODS

### 2.1 Chamber and setup

Climate chamber with dimensions of 4.7 m x 6 m x 2.5 m (W x L x H) was used to perform full-scale experiments. Piston flow was supplied upwards through the perforated floor of the chamber. Its velocity was kept lower than 0.06 m/s, i.e. close to quiescent environment. The air was exhausted through an opening (0.38 x 0.38 m<sup>2</sup>) in the ceiling (Figure 1a). The chamber had six ceiling light fixtures. The air temperature inside the chamber was kept at 23°C with 40% of relative humidity. The same temperature was maintained on the surfaces of the chamber's ventilated walls in order to avoid temperature asymmetry and additional air movement.

A breathing thermal manikin was used to resemble a seated person. The manikin was placed in the center of the chamber. A table was positioned in front of the manikin at distanced 10 cm from its abdomen. The breathing thermal manikin was positioned with its hands on the table and inclined backwards (Figure 1b).

The breathing thermal manikin had 23 body segments. It was simulating an average Scandinavian woman (height 1.7 m) with realistic body size and shape. The surface temperature of manikin's body was kept similar to the skin temperature of an average person in a state of thermal comfort at the studied conditions (room temperature and activity). Thus realistic FCF around the manikin was established. The manikin was wearing a tight clothing (T-shirt, underwear, tights, socks and sports shoes) with a total clothing insulation of 0.40 clo. Below the setup there was a wooden plate (2 m x 1.21 m) preventing the piston flow to interfere with the free convection flow around the manikin's body (Figure 1b).

The manikin was inhaling and exhaling with the help of artificial lung. The exhaled air was heated to 34°C and was not humidified. The pulmonary ventilation rate for light sedentary activity, 6 L/min, was adjusted. The breathing cycle was repeated with frequency of 10 times per minute. It consisted of 2.5 sec inhalation through the nose, 2.5 sec exhalation through the mouth and 1 sec of pause. Experiments without breathing and with the breathing were performed and compared.

A VC was placed on the chair. It sucked air through 8 pairs of openings and rejected it outside the chamber. The air was sucked at flow rates of 1.5 L/s, 3.0 L/s and 5.0 L/s.

A PV, named round movable panel (RMP) (Bolashikov et al., 2003), was used during some of the experiments to supply air transverse to the FCF and opposing to the flow of exhalation. The supply air terminal device (ATD) of the PV was with round shape (diameter of 0.185 m) and supplied the air through a honeycomb. The RMP supplied the air with low turbulence intensity and little mixing with the surrounding air. The RMP was fixed on the table and the ATD was positioned 30 cm away from the manikin's mouth. It was supplying the clean air from outside the chamber at 23°C. The ATD supplied the air with flow rate of 3 L/s and 6 L/s with velocities measured 30 cm away from the manikin's mouth 0.2 and 0.4 m/s, respectively.

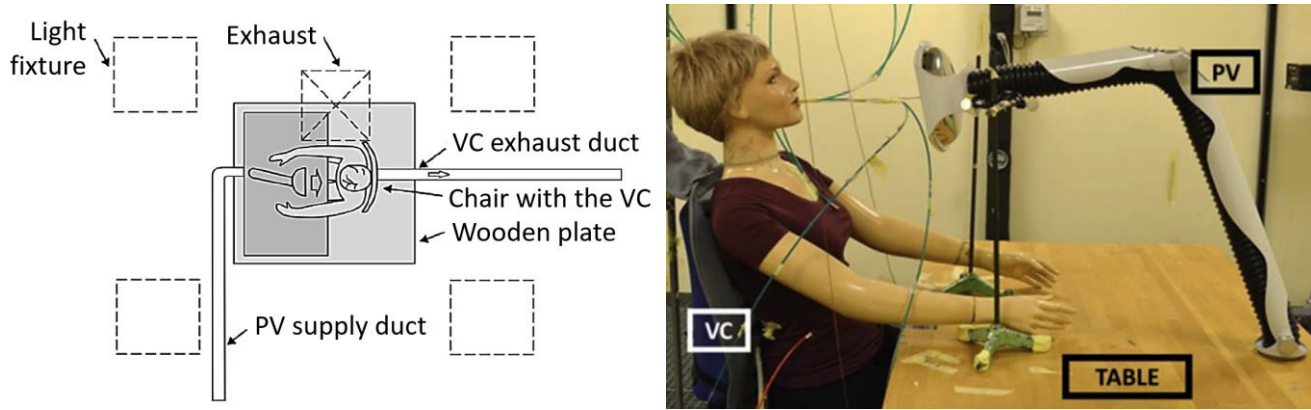


Figure 1: a) The sketch of the experimental setup (Kierat et al., 2018) and b) The photo of the setup (Bivolarova et al., 2017)

The air temperature was measured with a micro bead VECO thermistor (time constant 0.12 s) with a sampling frequency of 16 Hz (accuracy less than  $\pm 0.1$  K). The multichannel low velocity thermal anemometer AirSpeedSys 5000 with omnidirectional velocity sensor was used to measure the air speed, which is referred in this paper as air velocity (sensor Electronic, 2017). Its sampling frequency was 8 Hz (accuracy of  $0.02 \text{ m/s} \pm 1\%$ ).

The thermometer and anemometer were placed 1 cm away from the lips of the manikin, symmetrically and slightly to the sides below the nostrils, in a way to capture the exhalation jets from the nose (see Figure 2 a and b).

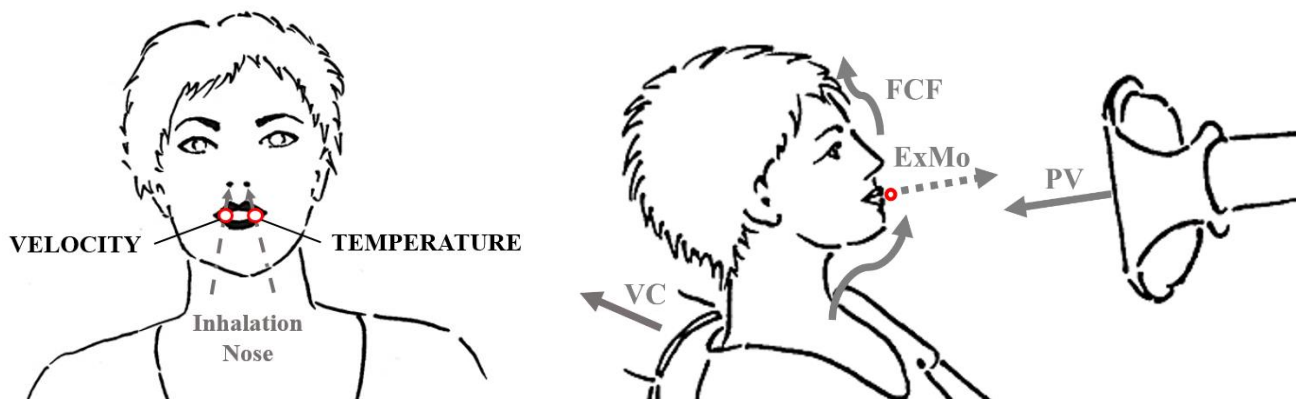


Figure 2: a) front view of the manikin with designated locations of the measuring locations of the velocity and temperature sensors and b) side view of the manikin with the generated airflows in the BZ.

The temperature and velocity were measured continuously at different combination of interacting flows, i.e. FCF, exhalation flow and PV flow. Because of the fast response of the measuring instruments it was possible to recognise and select only the exhalation periods of the breathing cycle. The data were analysed only for the exhalation periods of the breathing cycles (Figure 3). Averaged data obtained for at least 52 breathing cycles are presented in the following chapter.

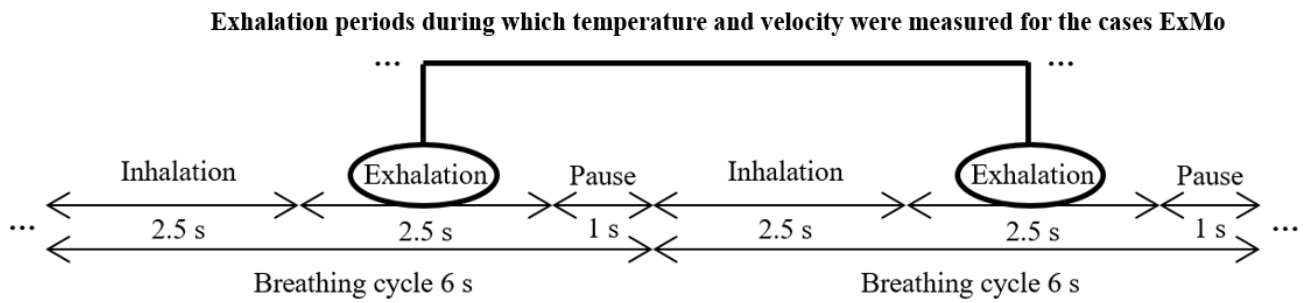


Figure 3. The selection of the exhalation periods from the breathing cycle for which the analysis of the measured temperature and velocity was made.

### 3 RESULTS AND DISCUSSION

The effect of the Exhalation jets from the Mouth (ExMo), the VC exhaust flow and the PV transverse flow as well as their combinations on the measured temperature and velocity are presented in Figures 4 and 5. The bars with black filling mark the averaged values of temperature and velocities measured during the experiments with No Breathing (NoBr) and the columns with oblique lines show the average values of the velocity and temperature during the exhalation periods only.

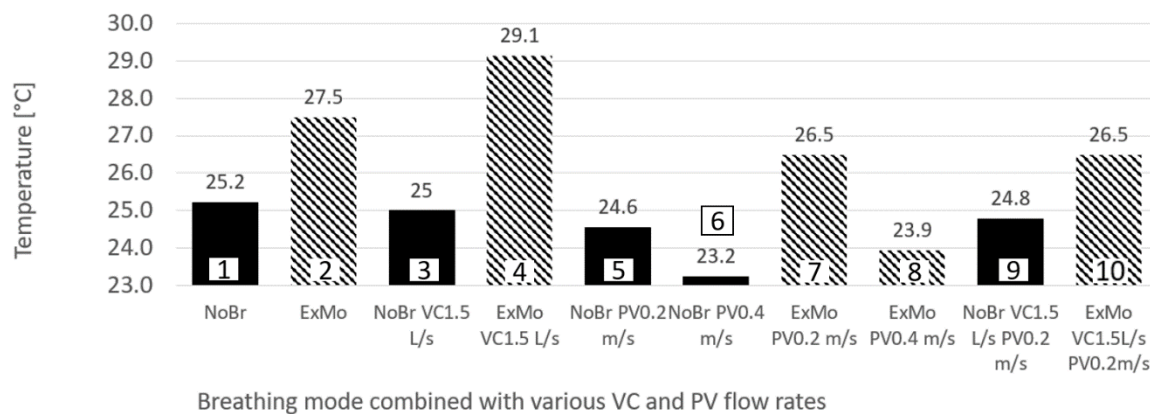


Figure 4. The effect of the ExMo, VC and PV combined on the Temperature in the BZ

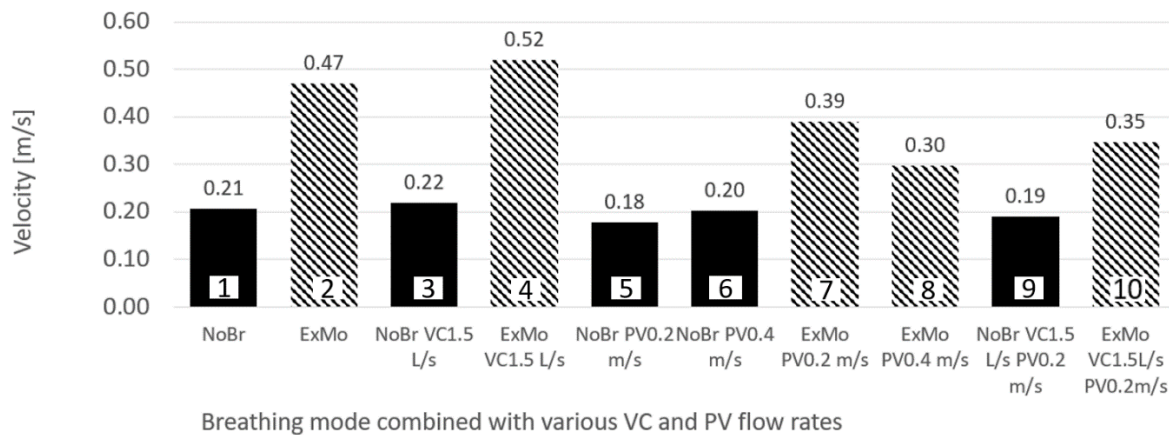


Figure 5. The effect of the ExMo, VC and PV combined on the Velocity in the BZ

In the figures, the first two bars compare the effect of the FCF ('NoBr') and ExMo on the temperature (Figure 4) and velocity (Figure 5). The temperature of the upward FCF was 25.1°C with velocity of 0.21 m/s when the manikin is not breathing and the VC and the PV were switched OFF. When the

manikin was exhaling, the temperature and velocity increased to 27.5°C and 0.47 m/s, respectively. It is visible that the exhalation jets from the mouth in the BZ were stronger compared to the FCF flow alone, because they were warmer, faster and could transversely brake the FCF (Figures 4 and 5, bars 1 compared to bars 2).

There was a slight effect of the VC visible when the VC worked at 1.5 L/s. The VC at 1.5 L/s combined with only the FCF showed almost no difference in the results compared to the reference case “NoBr” (Figures 4 and 5, bars 1 compared to bars 3).

Combined with breathing, the presence of the VC was investigated at three different flowrates (1.5 L/s, 3.0 L/s and 5.0 L/s). However the measured temperatures and velocities between the three flow rates were similar to VC 1.5 L/s. The temperature at VC 3.0 L/s and 5.0 L/s were 28.5°C and 28.6°C and the velocity 0.45 and 0.42 m/s, respectively. When the ExMo were present, it was possible to observe an increase in the velocities compared to the case, where the VC was OFF (Figure 5, bar 2 compared to bar 4). The presence of the VC decreased the temperature in the BZ, because the FCF was weakened by the VC and cooler surrounding air was entrained (Figure 4, bar 1 compared with bar 3). The upward FCF was slower and thus the downward exhalation jets from the mouth could achieve higher velocities in the BZ when the VC was in operation (Figure 5, bar 2 compared to bar 4). Previous studies (Bivolarova et al., 2017 and Kierat et al., 2018) showed the importance of the VC but with regard to the concentration of body generated pollution.

When PV was ON without breathing, the temperature decreased with increasing flowrate of the PV, because the PV applied cool air at 23°C into the BZ and thus in proportion to its flow rate’s strength penetrated the FCF (Fig. 4 and 5, bars 5 and 6 compared to 1). With PV working at 0.2 m/s the velocities at the breathing zone slightly dropped compared to the case without PV (Fig. 5, bar 5 comp. to 1). The PV flow (transverse to FCF) was blocking the FCF, which resulted in lower velocities at the measuring point. When the PV supplied the air at 0.4 m/s the velocities at the BZ again increased because the PV flow became stronger than FCF (Fig. 5, bar 6 comp. to 5). The results showed that the PV flow at 0.2 m/s did not penetrate the FCF and but was able to penetrate it at 0.4 m/s.

The addition of ExMo to the cases of PV (0.2 and 0.4 m/s) increased both the temperatures and velocities at the breathing zone compared to its absence (Fig. 4 and 5, bars 5 comp. to bars 7 and bars 6 comp. bars 8). This indicated that the opposing exhalation jets from the mouth were stronger compared to the flow from the PV. The temperatures and velocities were higher in case of PV at lower flowrate (Fig. 4 and 5, bars 7) compared to the PV at higher flow rate (Fig. 4 and 5, bars 8). This confirmed that the opposing PV flow reached deeper to the BZ, where it cooled and blocked the exhalation jets.

The use of the PV flow at 0.2 m/s combined with the VC at 1.5 L/s compared to the VC alone at 1.5 L/s decreased the temperatures and velocities compared to the VC at 1.5 L/s (Fig. 4 and 5, bars 9 comp. to bars 3). This was because the cool transverse PV flow was applied in the BZ. ‘NoBr VC1.5 L/s PV0.2 m/s’ compared to the PV at 0.2 m/s showed that the VC almost didn’t affect the temperatures and velocities (Fig 4 and 5, bars 5 comp. to 9). The effect of the PV flows was stronger compared to the effect of the VC flows.

By adding the ExMo to ‘NoBr VC1.5 L/s PV0.2 m/s’ the temperatures and velocities increased compared to their absence (Fig. 4 and 5, bars 9 and 10). Compared to ‘ExMo’ and ‘ExMo VC1.5 L/s’, the velocities and temperatures decreased (Fig. 4 and 5, bars 10 comp. to bars 2 and 4). This reveals the importance of the PV flows for IAQ and PAQ even at lower flowrates of the PV. Interestingly, when bars 10 were compared to ‘ExMo PV 0.2 m/s’ – bars 7, the temperatures remained the same, however the velocities dropped. The combination of VC at 1.5 L/s and PV at 0.2 m/s was less effective when penetrating into the BZ and reaching PAQ and IAQ compared to the PV at 0.4 m/s, with or without exhalation flows (Fig. 4 and 5, bars 9 compared to bars 10).

## 4 CONCLUSIONS

The exhalation jet from the mouth was stronger compared to FCF flow alone. The results showed that the simulation of the exhalation flow is important when studying temperature and velocity field at the breathing zone. The VC can be used to control the strength of the FCF. However, in the present design the amount of the exhausted flowrate wasn't important. The PV penetrated the FCF at 0.4 m/s but not at 0.2 m/s. The results indicated that the exhalation flows were dominant to the PV flows. The VC at 1.5 L/s didn't affect the performance of the PV at 0.2 m/s. The use of the PV alone at 0.4 m/s was able to penetrate effectively the FCF and improve IAQ and PAQ compared to PV at 0.2 m/s combined with VC at 1.5 m/s.

## ACKNOWLEDGEMENTS

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